Photogeology and Geomorphology of Parsoli-Bichor Syncline, Chittorgarh District, Rajasthan

BY

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CERTIFICATE

This is to certify that Mr. Syed Ahmad Ali has completed his research work under my supervision in partial fulfillment for the award of degree of Master of Philosophy of the Aligarh Muslim University, Aligarh. This work is an original contribution to our knowledge of geomorphology and photogeophysical expressions of the Vindhyan Basin in Parsoli-Bichor area of Rajasthan.

He is allowed to submit the work for the M.Phil.degree of the Aligarh Muslim University, Aligarh.

30th June, 1982

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INTRODUCTION

General Statement

The dissertation presents the geomorphology, photogeology and structural fabric of the Parsoli-Bichor syncline and adjacent areas in the Vindhyan Basin of Rajasthan. During the present investigation the data generation was attempted through remote sensing techniques with limited ground truth scanning. The study was directed to integrate tonal, textural and relief signatures of the area for synthesis of lithostratigraphy and geomorphic units. Micro-lineament, trend incidence density and intersection fabric linearity were photo-geophysically analysed for the interpretation of stress trajectories that led to the structural evolution of the area.

Areas and Location

An area of about 350 sq. km. was investigated in the Vindhyan Basin of Rajasthan. It forms northern part of Chittorgarh district, Rajasthan, covered by parts of the latitudes 25°00' to 25°15' and longitudes 74°45' to 75°00' and is included in the Survey of India toposheet No. 45K/16 (Fig. 1).

Accessibility

Chittorgarh is the nearest railway station on the Ajmer-Khandwa metre guage line of the western railway which is about 25 kilometers west of the area. The investigated area is approachable by road from Chittorgarh by the Chittorgarh-Bundi road which passes through Basi, Parsoli and Bichor, which are important villages in the area. Almost all the villages in the studied area are connected by good cart tracks, which are jeepable in dry season.

Previous Work

The earliest record about the geology of the area is by C.A. Hacket (1881), B.C. Gupta (1934) and A.M. Heron (1936) remapped the area. They have suggested that the granites between Chittorgarh and Bhilwara are equivalent to Bundelkhand Granite and referred to the pre-Vindhyan metasediments as the Gwalior facies of the Aravallis. Vindhyans were distinguished into Nimbahera Limestone, Suket Shales, Kaimur Sandstone, Panna and Jhiri Shales, Rewa Sandstones, Ganurgarh Shales, Bhander Limestone, Samria Shales and Lower Bhander Sandstone. Iqbaluddin (1962-63 and 1963-64) remapped the area and followed Heron (op. cit.) in the classification of the Vindhyan sedimentaries. He, however, considered the granite exposed in the Berach valley as intrusive into the pre-Vindhyan metasedimentary sequence, which be assigned to Bhilwara Group. Balmiki Prasad (1981) has suggested a revised classification for the Vindhyans and has separated the lower Vindhyans of Rajasthan into Basal Khairmalia Group, Sawa Group, Lasrawan Group, Khorip Group and Upper Vindhyans into Kaimur Group, Rewa Group and Bhandor Group. Prasad and Sharma (1977) described the geometry of the Great Boundary Fault of Rajasthan and Iqbaluddin et al. (1978) discussed the genesis of the Great Boundary Fault of Rajasthan under a centrifugal stress model.

Scope of the present work

The present investigation was directed to work out the spectral and geotechnical signatures of lithounits, geomorphology and structural fabric of the Vindhyan sedimentaries in Parsoli-Bichor syncline through photo-interpretation techniques. Therefore mapping was confined to the Vindhyan Basin in Parsoli-Bichor area. The mutually supporting evidence of various photo-recognition and geo-technical elements has helped in interpretation of lithology, structural patterns, style and geometry and in deciphering the stratigraphy of the area. The report presents the data collected in the laboratory in the course of detailed stereoscopic study of aerial photographs and the interpretations were made through convergence of evidence based on these data. Ground controls were obtained in selected areas around Parsoli and Bichor syncline from external sources.

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PHOTO-GEOLOGICAL MAP OF PARSOLI-BICHOR SYNCLINE CHITTORGARH, RAJASTHAN

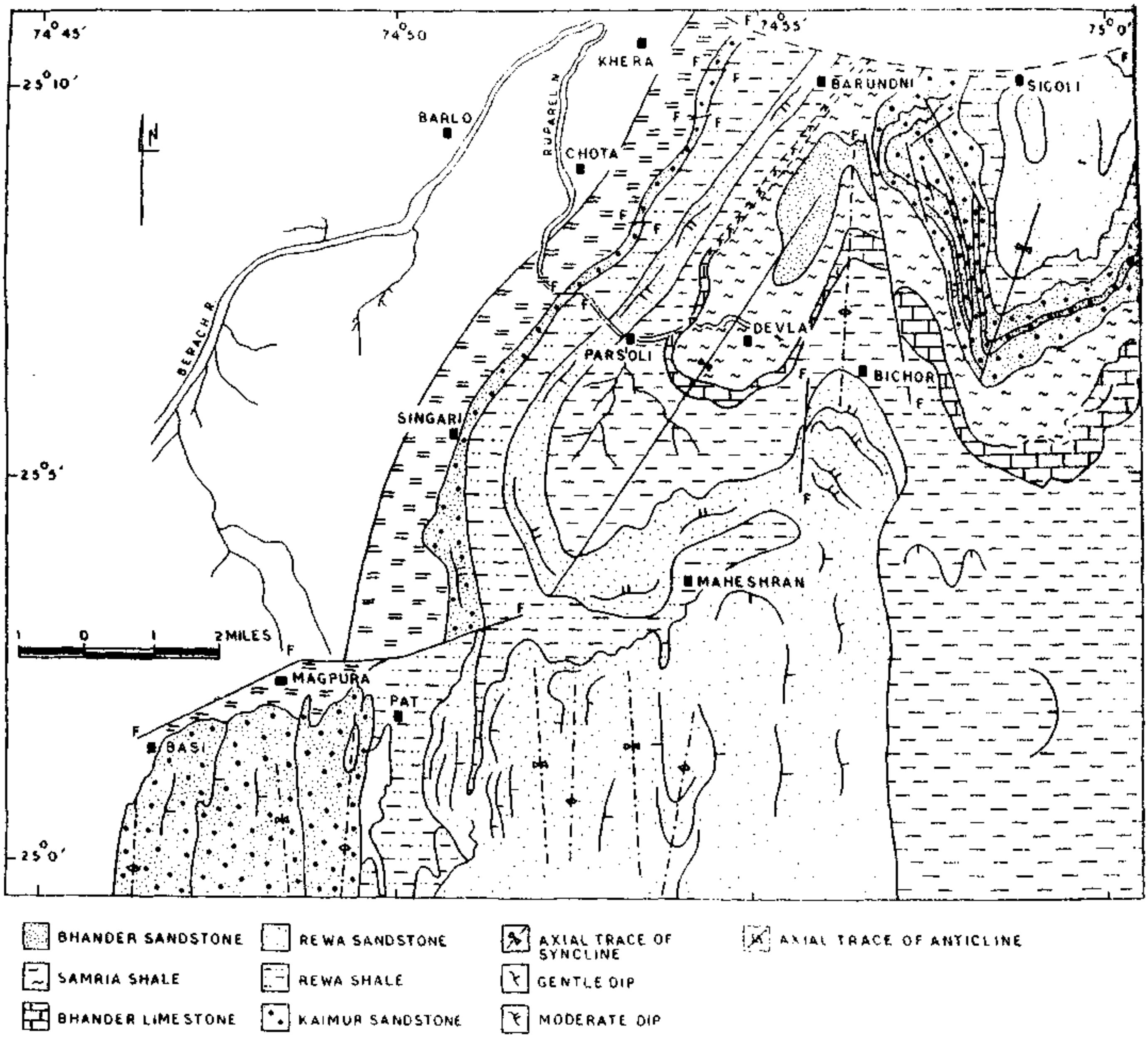

FIG.1

The study included :-

1. Photogeomorphological mapping of the area.
2. Photogeological mapping of the area.
3. Photogeophysical studies on microlineament trend, intersection and incidence densities.
4. Selective ground truth scanning.
5. Laboratory work.

An attempt has been made here to analyse the incidence density and intersection fabric linearity through Rolling Mean Analysis for interpretation of the stress trajectories responsible for the development of the present state of finite strain of the area. The technique developed will be useful for interpretation of stress environments of cratonic regimes.

METHODOLOGY

Specification of photographs

A total of 19 photographs were used for the present study. The details of photographs are as follows :

Strip no.	Photo nos.	No. of photos used in each strip
148	39-44	6
137	40-46	7
140	37-42	6

Camera used - Earle IX

Focal length - 152 mm.

Format size - 23 cm X 23 cm

Scale - 1 : 63,360

Type of paper - Double weight, Semi matt.

Overlaps - Forward 60-70%

Lateral 15-20%

Quality of Photographs

The photographs are good quality and show good definition, excepting along the margins. The photographs do not suffer much from image displacement. Since the relief variation in the area are not of very high magnitude no actual gaps or effective gaps due to short overlaps were found. The strips also do not show any excessive crabbing.

Method of Study

The work of preparing an uncontrolled mosaic to the preparation of the final map was carried out in following steps :-

1. The photographs were laid out in an uncontrolled mosaic. Mismatching between adjacent photographs was not found more than a mm.

2. A general idea about the geological and geomorphological set-up of the area was obtained by a careful study of the mosaic.

3. Important cultural and topographical features were annoted on photographs with the help of relevant toposheets of 1 : 63,360 scale.

4. Detailed stereoscopic study of each photo pair was made and all the details relevant to the study and consistent to the scale of photography were marked run-wise on separate Koda-trace overlays.

5. Identification of different geologic and geomorphic features was based on convergence of evidence offered by different photo-recognition and geo-technical elements.

6. The Koda-trace overlays of different strips were then arranged by matching topographic features to form a mosaic.

7. A tracing paper was laid over this uncontrolled mosaic (overlays) and all the geologic, cultural and physiographic data was traced over the tracing sheet. In the lateral overlap area the details for the upper half area were traced from the Koda-trace overlay of the upper strip and for the lower half from the lower strip.

8. All important natural and man-made features were annotated and graticule lines marked with the help of 1 : 63,360 toposheets.

9. Geomorphological, geological and other plates were prepared.

10. Xerox copy of different plates were obtained.

ACKNOWLEDGEMENT

I acknowledge with deep gratitude the guidance and encouragement I received from Mr. Iqbaluddin, my supervisor. He was a constant source of inspiration.

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Last but not least I avail this opportunity to acknowledge the blessings and good wishes received from my father, Mr. Syed Amjad Ali and elder brothers Mr. Syed Akhtar Ali and Mr. Syed Amir Ali.

Chapter II

PHOTOGEOMORPHOLOGY

General Statement

Geomorphological study of the Parsoli-Bichor area, Chittorgarh district, Rajasthan was carried out in an attempt to establish correlation between landforms and solid geology of the area (Fig. 2). The study presents an account of the constructional and erosional landforms and describes their spectral and geotechnical expressions.

PLANATION SURFACES

The planation surfaces which have been recognised roughly corresponds to 379 m and 432 m elevations. For purpose of description these have been designated as Parsoli and Berach Surfaces respectively.

Parsoli Surface

It is characterised by development of a planar surface roughly corresponding to an elevation of 432 m. It is the oldest surface in the area and is morphologically expressed as Vindhyan plateau in the Parsoli-Bichor area. Its surface expressions are isolated erosional peaks and structural hills in the metasedimentary tract of the Manglwar Complex to the north of the

PHOTO GEOMORPHOLOGICAL MAP OF PARSOLI-BICHOR SYNCLINE CHITTORGARH, RAJASTHAN

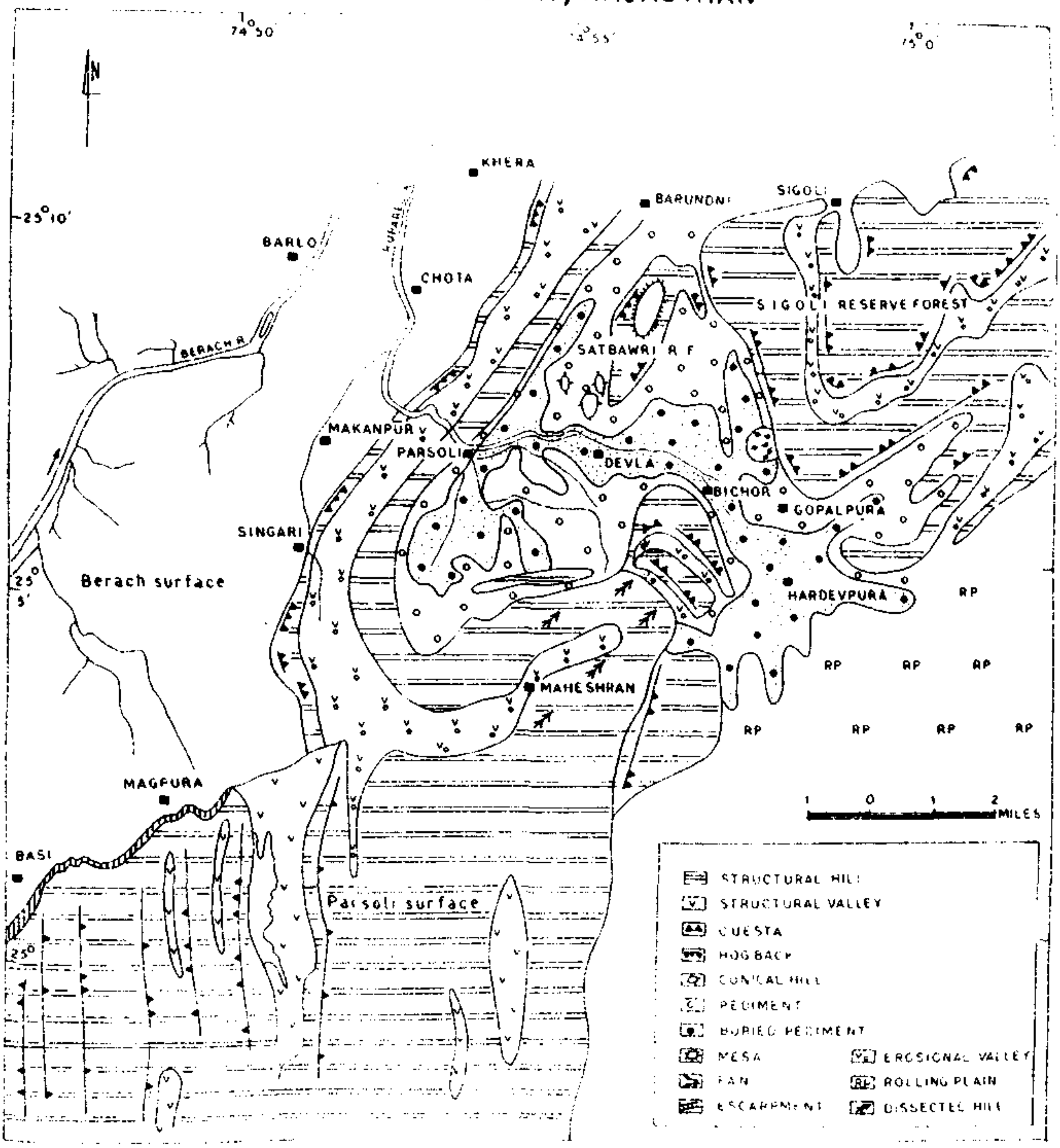


FIG.2

Dynamically the surface appears to have been evolved dominently by process of sheetwash which was controlled by a south westerly to southerly regional slope. The dating of this surface will be hazardous in the absence of any well defined markers, however, taking the regional setting of Rajasthan into consideration it is ventured that it will beolder than crataceous which is a 288 m surface in adjoining tract of Banswara (Iqbaluddin, 1982).

Berach Surface

The surface represented by the Berach valley and the adjoining rolling plains of the Mangalwar Complex corresponding roughly to 379 m elevation has been designated as Berach surface. The homogeneity of the surface is locally punctuated by the "inliers" of older Parsoli surface, which is present as isolated hills of hard and resistant lithounits.

The development of the Berach surface has been dynamically controlled by process of deep chemical weathering followed by sheet erosion. The spatial spread of the surface has been controlled by lithology. The rocks of Mangalwar Complex and Berach Granite being dominantly feldspathic in composition were amenable to chemical weathering whereas Vindhyan clastogenes withstood the chemical weathering in the area and thus resisted erosion in the period that elapsed the generation of Parsoli surface. The differential response of Mangalwar metasediments and Vindhyan clastogenes to mass wasting processes led to the generation of Berach surface in the area north of Vindhyan Plateau. The dating of this surface in absence of any marker horizon is difficult. As a rough approximation it is suggested that based on its relative elevation to Parsoli surface it is younger than Parsoli and older than Cretaceous surfaces in Rajasthan (Iqbaluddin, op. cit.).

GEOMORPHIC UNITS OF THE PARSOLI SURFACE

The componental geomorphic units of the Parsoli surfaces were studied in details. The units have been mapped under stereomodels on the basis of homogeneity of tone, texture, drainage pattern, lithological characteristics and the structural fabric of the landscape. The units recognised on the Parsoli surface can be classed as erosional and depositional. The study was directed to evaluate the geometry of the landforms through convergence of photo-recognition and geotechnical elements. Dynamics of the evolutionary process was interpreted taking local factors into consideration.

Structural Hills

In the Vindhyans the sandstone units of Kaimur, Rewa and Bhander Groups have attained higher elevation as a result of tilt acquired by the lithounits in response to deformative stress. The height of the elevated surface was accentuated by down cutting at the base of the hills by the erosive action of the local drainage. The spatial spread of the structural hills in the area roughly coincide with the spatial deposition of sandstone beds. These hills are developed south of Sigoli in Satbawari R.F. area, west of Basi and along the periphery of the Parsoli-Bicher Syncline.

Under the stereomodels the structural hills are characterised by medium to dark grey phototone, fine texture and sharp very coarse external annular and sub-dendritic drainage with gentle V-form valley profile. The first order channels are joint controlled.

Structural Valleys

The drainage in the area has been locally controlled by spatial spread of open, shallow synclines which provide readymade channels for the surface run-off. The characteristics feature of structural valleys in the area has been rectilinearity of trend and at times their convergence with the erosive channels at non-accordant levels. Structural valleys west of Basi are seen along north-south trend coinciding with axial trace of synclines in the area.

In stereomodels the units are expressed as synclinal depressions with shallow uniform valley slope. The slopes are accordant with dip of beds along the valley. These valleys are characterised by linearity of drainage segments and at places by non-accordant levels between structurally controlled tributaries and main erosive drainage channels.

Erosional Valleys

In the area, the development of the erosional valleys are morphotectonically controlled. Spatially these valleys are present south of Sigoli, west and south of Parsoli and south of Bichor. The valley profile is sharp, asymmetric and controlled by spatial distribution of the shale beds. Except in the area south of Parsoli the valley profiles are characterised by consequent slopes in the west and subsequent slopes in the east determined by the erosive action of the channels. The consequent slopes are controlled by dip of beds. The valley development south of Parsoli has been evolved by the headward erosion of the drainage channel. The localisation of the erosive activity along the channel in the upper beds (sandstone) has been controlled by the development of tensile regime along the southern limit of the Parsoli-Bichor syncline manifested by an E-W trending culmination axis in the area.

The valleys are having steady slopes, the tributaries are joining the main channels along accordant levels. Under stereomodels the erosional valleys are characterised by medium to dark grey phototone, cultivation patches, grass fields, thick soil cover, asymmetric profile and linear correlation between valley axis and local structural trends in the area.

Cuestas

In the structurally deformed Vindhyan sandstone wherever the dips are low, the bedding planes have been carved out into ridges with asymmetric profiles. The dip slopes are long with low gradient. The obsequent slopes are steep and short. These features are characterised the cuestas in the area south of Basi, south of Sigoli and south of Bichor.

Under stereomodels the cuestas have been recognised by the rectilinearity of the structural trends and asymmetry of slopes. Steeper slopes being short and gentler slopes being long. The texture of the steep slopes is generally rough and tone is dark. Along gentler slopes in cuestas the tone is light and texture is smooth. The spatial continuity is generally punctuated by consequent drainage in the area.

Hogbacks

The Kaimur sandstone, west of Parsoli and Bhander sandstone on the western flank of the Satbawari Reserve Forest show strike ridges with nearly symmetrical profile. The slopes of the ridges have moderate gradient. The angle (around 45^{o}) of the slope roughly coincide with the dip of the beds in the area. The continuity of the structural trends has been broken by local drainage which cut across the strike. The hogbacks under stereo-models are like cuestas but are separated by the near uniformity of consequent and obsequent slopes, symmetry of the profile and relatively steeper and shorter slopes along the profile.

Conical Hill

In the Satbawari Reserve Forest area the Semria Shales have given rise to three conical hills which are characterised by the development of non-cylindrical geomorphic surfaces. Morphotectonically the development of the conical hills is controlled by joints. The erosion have been selective in the shales and an intercalatory sandstone bed has provided resistent cap which has helped to carve out this geomorphic unit. Under stereomodels the unit occurs as idiomorphic element recognised by radial slope and sharp conical peaks. The slope characteristics are uniform in all directions and profile sections are symmetrical.

Mesa

In Satbawari Reserve Forest the Bhander Sandstone in the hinge zone of Parsoli-Bichor syncline has given rise to a table land about 1.5 km long and .75 km wide. It has nearly horizontal top surface which reflects the sub-horizontal dips of the sandstone beds which have carved the surface. This unit has been assigned as Mesa.

Under stereomodels it is recognised by sharp slopes along the sides of the flat-topped erosional surface. The slopes have first order drainage channels, which due to steep gradient have not evolved into second order channels along limits of this geomorphic unit.

Pediment

Smooth rock cut slopes at the base of the structural hills in the Parsoli-Bichor syncline have been mapped as pediment. The surface has been carved out of the shale beds in the area. The outcrop density on the pediment surface is low. The erosional surface is generally covered by a thin veneer of soil. Under stereomodel the pediment has been recognised by low relief, darker phototone than the adjacent hills, abundance of grass lands and subdendritic drainage pattern.

Buried Pediment

The pediment surface in the Parsoli-Bichor syncline along the Ruparel sub-basin has developed a surficial cover of gravel, sand and clay, showing fining upward sequence. The deposit of silt and gravel on the rock cut surface has been mapped as buried pediment in the area. The boundary of the area is sinuous roughly representing the periphery of an ancient natural reservoir developed due to erosive resistance of Barundni ridge of the Rewa Sandstone Formation in the eastern limb of the Parsoli-Bichor syncline.

The rejuvenation of the Ruparel <u>nala</u> after the burial of the pediment has led to the cutting of its own flood plain along the channel axis leading to the emergence of buried pediment.

Under stereomodels the unit is recognised by extensive cultivation and matted texture of human influence on the aggradational surface.

Fan

North-east of Bichor on the western escarpment face of the cuestas in the Sigoli Reserve Forest, the Kaimur Sandstone has developed a scree fan with curved distal margin and short rectilinear proximal margin. The handle is missing in the fan suggesting that it has been evolved not from a point source. The development of the fan has been possibly controlled by the receding fault line scarp in the area. The rectilinearity of the proximal outline suggest a line source for the development of fan.

Under stereomodels it has been picked up by radial relief and tonal contrast. The unit is characterised by lighter phototones in shades of grey.

Escarpment

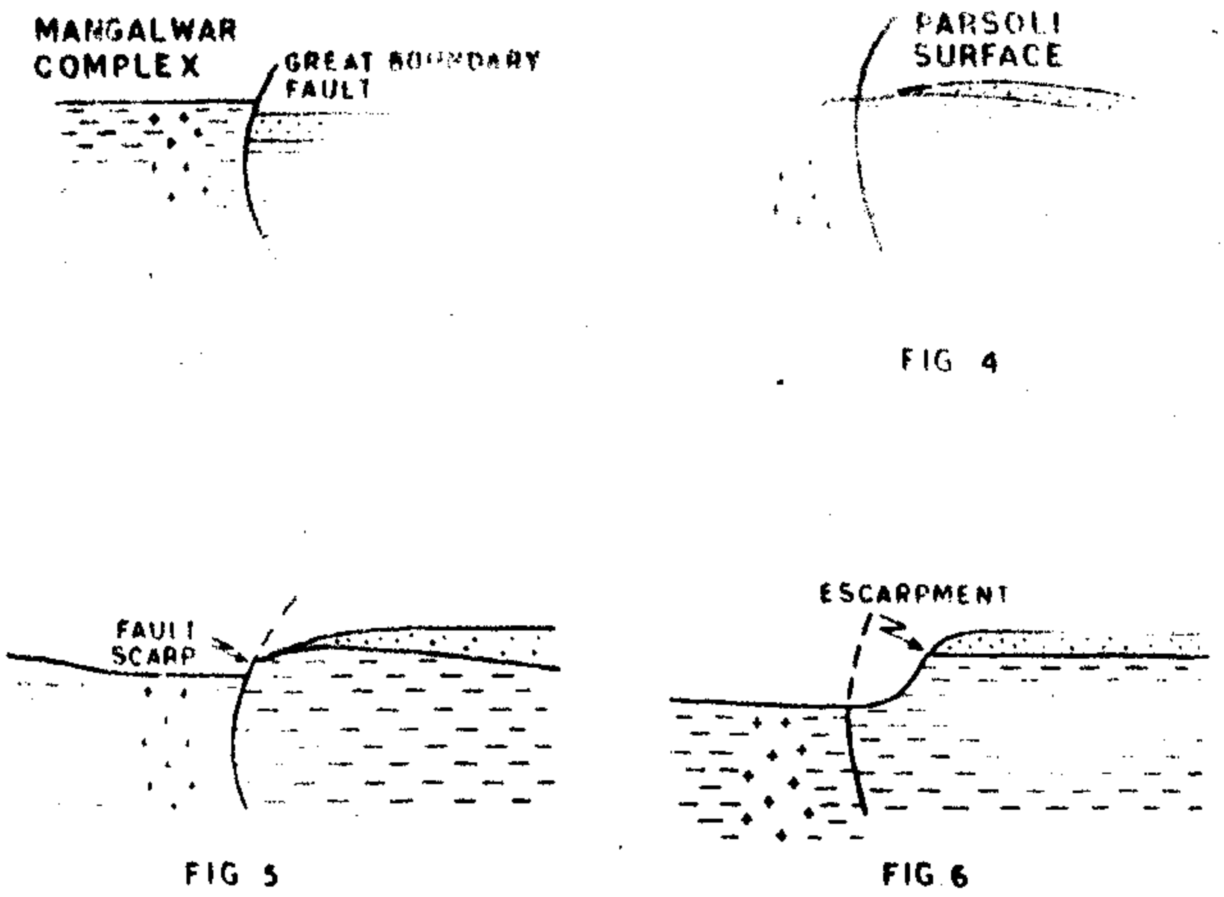
South of Basi the Kaimur Sandstone is exposed as a vertical monolith across the Great Boundary Fault of Rajasthan. The steeper face of the cuestas overlooking the Berach surface of the Mangalwar Complex forms an escarpment. The evolution of this escarpment has a complex history. The higher rate of erosion of the metasedimentary sequence of the Mangalwar Complex and Berach Granite led to the development of a fault line scarp in the area (Figs. 3-5).

Figure 3 Curviplanar Great Boundary Fault showing elevated Mangalwar Complex, towards the close of Vindhyan period.

Figure 4 Evolution of Parsoli surface due to sheet-wash and generation of southwest and southerly slope. First geomorphic cycle.

Figure 5 Deep chemical weathering and sheetwash during second geomorphic cycle exhumed the fault plane.

Figure 6 Retreat of the scarp face due to rapid erosion of Suket Shale during third geomorphic cycle.



SCHEMATIC DIAGRAM SHOWING EVOLUTION OF ESCARPMENT IN THE VINDHYAN BASIN OF RAJASTHAN

The erosion of the resistant cover of Kaimur Sandstone from the fault line scarp (Fig. 6) led to rapid erosion of the softer Suket Shales across the fault line scarp which resulted in retreat of the scarp face and evolved the scarpment in the area.

Under stereomodels the unit is recognised by steeper slope, darker phototone and barren surface devoid of any vegetation.

Rolling Plains

East of Begun Ganurgarh Shales and Bhander Limestone have given rise to rolling plains. The morphotectonics of the rolling plain is controlled by structural disposition of low dipping, undulatory bedding plane in the Ganurgarh Shales and over lying Bhander Limestone outliers. The inhomogeneity of the surface relief has been accentuated by the differential erosion of the intercal-atory sandstone beds and shale in the Ganurgarh Shales horizon.

Under stereomodels the unit is recognised by uneven texture, sub-dendritic drainage with low inhomogeneous relief.

DISCUSSION

The morphological study of various geomorphic units in the area has helped in evolving a model for the landscape evolution of the Vindhyan Basin in Rajasthan.

The geomorphic evolution of the area has been polycyclic. The first geomorphic cycle in the Vindhyan Basin of Rajasthan was an erosional cycle which led to the development of a planar surface roughly corresponding to 432 m. elevation. The surface was carved from a structurally and lithologically inhomogeneous envelop, dominantly by a process of sheetwash controlled by southwesterly to southerly regional slope.

The second cycle was dominated by insitu weathering of the Vindhyans and the metamorphites of Mangalwar Complex and Berach Granite in the area adjacent to the Great Boundary Fault of Rajasthan. The initiation of the second cycle was characterised by deep chemical weathering followed by sheetwash that generated the 379 m. Berach surface which characterise the plain tract adjacent to the Vindhyan Basin of Rajasthan in Chittorgarh district.

The evolution of the Berach surface marked a lowering of base level of erosion. This triggered the dynamic processes of gulley erosion and valley development on the Parsoli surface. The impact was dissection and generation of inhomogeneities in the planar surface in the Vindhyan Basin. The effects of this rejuvenation of landscape architeature during the second cycle are seen as development of pediments and retreating hill fronts in the area.

Local pauses in the erosive activity have taken place as seen by development of buried pediments in the area. The aggradational phase possibly represents micro-process in the total model of landscape evolution of Vindhyan Basin in Rajasthan which has been dominantly erosive.

The third cycle of the landscape evolution is characterised by valley deepening of the drainage channels through cutting of their own aggradation surfaces (buried pediment) which was possibly triggered by lowering of base level of erosion subsequent to the generation of Berach surface as indicated by the mature sta e in the valley development of the Berach river. The local relief characteristics of the basic geomorphic units in the Vindhyan Basin appears to have been shaped by the third cycle which is still in its dynamic phase.

Chapter III

PHOTOGEOLOGY

General Statement

Photo characters of lithounits of Vindhyans in Parsoli-Bichor syncline have been described.

The Geology of the Parsoli-Bichor syncline has been established through convergence of spectral signatures of photographic elements and spatial characters of geotechnical elements. Lithological deductions were made through logical interpretation of photo recognition elements. Stratigraphy was worked out by concurrence and synthesis of observed spectral and spatial characters of lithounits with external information. The intent of this work is to present recognition elements which may serve as guides for rapid lithological mapping in the Vindhyan Basin of Rajasthan.

The lithostratigraphy of the Parsoli-Bichor syncline, spatial distributions and temporal correlation of the lithounit has been given in Table I.

Table I

Vindhyan Supergroup	Upper Vindhyan	Bhander Group	Bhander Sandstone	Greyish, hard, compact, massive, medium to fine grain, thinly bedded, bedding plane inhomogeneities seen as ripple marks, internal organisation manifested as cross-stratification. Joints are present.
			Samria Shale	Dull green to reddish, calcareous to sandy, local intercalations of sandstone beds, well bedded, bedding plane inhomogeneity locally seen as mud cracks.
			Bhander Limestone	Grey to pink, well bedded, locally intraformational bands are present towards the base. Few bands are of cement grade.
			Ganurgarh Shale	Subdued green to purple, sandy shales well bedded, bedding locally exhibit ripple marks, mud-cracks and internal organisation as cross-beds.

(contd.)

Table I(contd.)

Vindhyan Supergroup	Upper Vindhyan	Rewa Group	Rewa Sandstone	Grey, medium grain, unimodel, well sorted, locally gritty and conglomeratic towards top. Bedding well preserved, surface inhomogeneities are present as ripple marks and trough and planar cross-beds define internal organisation joints are common.
			Rewa Shale	Brown to dull green, soft and crumbling. Locally sandstone intercalation present, though by a large Lower Bhander Sandstone is missing as a marker horizon in the area.
		Kaimur Group	Kaimur Sandstone	Grey, medium grain, unimodel locally conglomerate intercalations. Bedding present as massive units, internal organisation locally seen as cross-beds. Highly recrystallised and jointed.
	Lower Vindhyan	Khorip Group	Sukot Shale	Dull green, sandy shales near top thinly laminated, external inhomogeneities and internal organisation are significantly absent in these shales.

SPECTRAL AND GEOTECHNICAL CHARACTERS OF LITHOUNITS

The photo characters of different lithounits of the area have been described below and synopsis of recognition elements has been given in Table II (See Appendix).

Suket Shale

In the western part of the Parsoli-Bichor syncline a narrow fringe of alluvial tract and isolated shale outcrops has been photogeologically mapped between the rolling plains of Berach valley and the hilly tract of the Vindhyan Basin.

The lithounit exhibits grey and vegetation light grey phototones. The textural signatures are fine in lithounit and uneven in vegetational cover. The drainage is external, dendritic and exhibit coarse density. Erosional resistance is low. Stratification is not discernable, boundaries are vague, surficial cover is thick and vegetation is present as grass field. The lithounit has been identified as shale. On the basis of local relationship of superposition the shale has been assigned to Suket Shale, of Khorip Group (Prasad, 1981).

The contact of the shale with Berach granite is obscure. Photo mozaic suggest the contact of the Pre-Vindhyans (Berach Granite and Mangalwar Complex, G.S.I., 1981) with Vindhyan sedimentaries, is a tectonic surface. It has brought in juxtaposition, the Kaimur Sandstone and Pre-Vindhyans rocks near Basi and Suket Shales elsewhere in the area. This tectonic contact between the Vindhyans and Pre-Vindhyans has been mapped as Great Boundary Fault of Rajasthan (Iqbaluddin et al., 1978).

Kaimur Sandstone

Sandstone ridges forming the western flanks of the Parsoli-Bichor syncline, west of Parsoli and the plateaus with cuesta slopes south of Basi and south of Sigoli have been assigned to the Kaimur Group of the Vindhyan Supergroup. On the basis of their local relationship of superposition with the underlying Suket Shale of the Khorip Group.

West of Parsoli the unit forms hogback strike ridges with nearly symmetrical profile. South of Basi and in the faulted plateau south of Sigoli it forms uneven cuestas with long dip slopes. This unit shows medium to light grey phototone, human influence has linear pattern, rocks have fine and vegetation exhibit sparse to uneven photo texture. The outcrop density of this unit is very high. The bedding is prominent and joints are present as transverse and longitudinal sets. It has a thin cover of soil and has external, coarse, dendritic drainage with gentle V-shape valley profile. The photo characters suggest that this unit may be sandstone. It exhibit conformable spatial relationship with overlying and underlying shales.

Rewa Shale

Succeeding the Kaimur Sandstone a horizon of argilleceous sequence has been mapped between the hogbacks of Kaimur Sandstone and the structural hills of Rewa Sandstone west of Parsoli. This horizon has been assigned to Rewa Shale on the basis of its spatial continuity, relationship of superposition and external information (Iqbaluddin, op. cit.). The horizon has been mapped from west of Barundni to Mahesran in the Parsoli-Bichor syncline and in the faulted plateau south of Sigoli.

The reflectance characteristics correspond to medium to light grey phototones in lithounit and the corresponding tones for vegetation and human influence are dark to dark grey phototones. The textural characteristic for the litho-types is fine, for vegetation it is uneven and human influence is exhibited as matted texture. The drainage is external, pattern is dendritic and density is coarse. The cross-sectional area of the first and second order drainage channels exhibit gentle V-form profile. Morphotectonically the unit is expressed as erosional valleys. The bedding characteristics are not clear, lithological boundaries are vague, surficial cover is thick, vegetation sparse, human influence expressed as cultivation patches and local habitation. Outcrop density is low. The logical deduction suggest the litho-type is shale.

Rewa Sandstone

Fringing the Parsoli-Bichor syncline a sandstone horizon has been mapped from Barundni to Bichor and it continues further south upto south of Mahesran. This horizon on the basis of the external information and its relationship of superposition with the underlying Rewa Shale has been assigned to Rewa Sandstone (Iqbaluddin op. cit). Another outlier of this sandstone has been mapped in the faulted plateau south of Sigoli. The correlation between the two isolated outcrops has been made on the basis of homogeneity of their spectral characters and geotechnical elements.

The rocks exhibit medium to grey phototone, the vegetation exhibit homogeneous light grey phototone, human influence present in the form of activities related to forestery is exhibited as light grey tone. The corresponding textural parameters for rock, vegetation and human influence are fine and sparse to uneven (in hogbacks and cuestas) and linear respectively. The drainage is external, pattern is dendritic and density is coarse. The cross-sectional area of the first order channels is present as gentle V-form profile. The litho-types exhibit high resistance to erosion, stratification is massive and clear at places exhibited as long cuesta slopes.Planner structural inhomogeneity are present in the form of two sets of micro lineaments. Structural trends confirm to a major syncline to a major syncline in the Parsoli-Bichor area. The surficial cover is thin, vegetation is exhibited as random growth of flora with short crowns. Morphotectonically the unit forms raised ground in the form of structural hills and plateaus. On the basis of logical deductions and convergence of the spectral and spatial characteristics, the unit has been identified as sandstone.

Ganurgarh Shale

Resting over the Reva sandstone along its dip slopes a conformable sequence of argilleceous rocks with arenaceous intercalations has been mapped as Ganurgarh Shales in the Parsoli-Bichor syncline and in the MAL of Nandwai.

The lithounit exhibit dark to light grey phototone. The tonal signatures, vegetation and human influence vary in shades light grey to dark grey. The textural pattern of litho-unit is fine, vegetation uneven and human influence exhibited as matted and uneven pattern. The drainage is external, sub-dendritic and very coarse. The cross-section of the first order channel is gentle V-form profile. The litho-unit exhibits low resistance to erosion. The outcrop density is poor. Locally the sandy intercalations form isolated outcrop. The bedding expression is poor and boundaries are vague. Jointing is significantly absent. The beds show gentle dips and exhibit rolling trends. Surficial material is thin, vegetation cover is in the form of grass fields and human influence exhibited local cultivation patches and habitations. The litho-unit has been interpreted as Sandy Shales.

Bhander Limestone

Overlying the shales isolated ruwares of limestone are seen in the Parsoli-Bichor syncline which have been assigned to Bhander Limestone horizon of Bhander Group (Iqbaluddin,op.cit.)

The limestone band has been traced more or less as a continuous horizon from near Parsoli to east of Satbawri Reserve Forest where its continuity is punctuated by a fault. The limestone band is again picked up to the east of fault with a strike separation of nearly one kilometer. The limestone band has been traced east of the fault from north-east of Bichor to Hardevpura. The continuity of this band has been traced on the basis of the micro relief though the outcrop distribution is scanty. The limestone horizon exhibits high reflectance which is manifested as light to light grey phototones. The texture is fine, drainage is external sub-dendritic and density is very coarse. The first order channels have gentle V-form valley profile. Its resistance to erosion is medium, stratification is clear, boundaries are sharp in inclined beds but vague in horizontally disposed layers e.g. near Hardevpura. The dips are low, surficial material is thin to absent, vegetation is absent, human influences present as small cultivation patches.

This unit is separated from the overlying shale horizon on the basis of its high reflectance and relatively higher resistance to erosion.

Samria Shale

South of Satbawri Reserve Forest near Devla, the shale outcrops are seen which have been assigned to Samria Shales of the Bhander Group (Iqbaluddin, op. cit.). The shales have low outcrop density. Occasional exposures are discernable in the Ruparel nala section.

The rocks exhibit medium to light grey phototone, vegetation exhibits light grey photone and human influence is seen in areas where the rocks are present as subcrops as light phototone. The rock texture is fine, vegetational texture is uneven, texture of the human influence in the subcrop areas are linear and matted. The drainage is external, sub-dendritic, very coarse and first order channels have gentle V-shaped valley profiles. Resistance to erosion is low except near Devla where they form conical hill. Bedding is poorly expressed, the boundaries towards the base are gradational and the superface of the formation has clear sharp contact. The structural attitude corresponds to synclinal closure at the southern end of the Satbawri Reserve Forest. The surficial cover is thin, the vegetation is sparse, human influence in the covered part is expressed as cultivation patches. The litho-unit has been inferred as Sandy Shales.

Bhander Sandstone

In the Satbavri Reserve Forest capping the Samria Shale horizon monolithic cover of sandstone is seen which defines the axial zone of the Parsoli-Bichor syncline. The sandstone on the basis of its local relationship of superposition and external information has been assigned to lower Bhander Sandstone (Iqbaluddin, op. cit.).

Sandstone forms a Mesa with sharp relief along the formational boundaries. It exhibits medium grey phototone, vegetational cover has dark grey tone, human influence is seen as linear patterns with light greytone.

The litho-texture is fine, vegetational texture is coarse, drainage is external, pattern is annular with very coarse density. The unit exhibits high resistance to erosion, stratification is clear and massive. The contacts are sharp and persistant. Three sets of joints are prominently seen. The sequence exhibits synclinal closure. Surficial cover is thin. Vegetation is sparse and human influence is exhibited by deforestation. The unit has been identified as sandstone.

DISCUSSION

The photo-recognition characters based on reflectance and landform characteristics can serve as guides for rapid lithological mapping in the Vindhyan Basin of Rajasthan. The photo-characters together with spatial relationship of the litho-units can be helpful in establishing stratigraphy of idiomorphic outcrops.

The lithology and outcrop distribution of limestone is difficult to interpret because of extremely low erosive resistance and near uniformity in the reflectance characteristics of limestone and the adjacent soil cover. It is recommended that photogeological mapping of limestone be done in the Vindhyan Basin of Rajasthan through extrapolation of ground truth obtained either by collection from external sources or by data generation.

Vegetation and human influence will not be reliable parameters though locally may provide useful information for logical interpretation of lithology by concurrence and synthesis of the photo-recognition elements.

Chapter IV

PHOTOGEOPHYSICS

General Statement

Strain generated linear photo-fabric was studied under Stereomodels through statistical and photo-interpretation techniques. These techniques of photogeophysics have been attempted in selected areas (Blanchet 1956, 1957; Mollard 1957, 1959; Lattman 1958; Henderson 1960; Haman 1964) for analysis of the structural fabric.

Photogeophysical techniques are directed to recognise characteristic patterns obtained from photogeophysical factors such as length of individual lineaments, their trend, lineament incidence density per unit area, lineament intersection density per unit area and spatial seperation between parallel to sub-parallel lineaments. The photogeophysical patterns sometimes can be correlated with geological factors.

In the present study the macro structural fabric was analysed through study of azimuthal disposition of the bedding. Stress regimes that gave rise to the macrofabric were evolved through micro-lineament analysis. The work presents the concurrence and synthesis obtained through convergence of photogeophysics and photogeology.

Methodology

The study was directed to generate structural data from photogeophysical and photogeological interpretations and the treatment of the data in terms of patterns and anomalies. The patterns and the anomalies obtained from photogeophysical techniques were interpreted in terms of stress regimes through correlation of the present state of finite strain in the area.

Generation of Data

For photogeophysical interpretations the bedding and joints were studied and identified under stereomodels through study of the spectral and geotechnical expressions of these elements.

Bedding :

Bedding was recognised on the basis of banded patterns of phototones, variable erosive resistance of lithologies, exhibited as micro-relief along the strike and as long cuesta slopes. The attributes of strike and dip were recorded on the overlays. Dip was recorded in terms of gentle (< 30) moderate (30-60) and steep (> 60). The strike variance was recorded on the overlays with reference to their spatial disposition in the area.

Joints :

Joints exhibited as micro-lineaments (Blanchet, op. cit.: Mollard, op. cit.; Haman, op. cit.) were identified under stereo-models through convergence of photo-recognition elements, exhibited as changes in micro relief, local rectilinearity of drainage channels, local linearity of vegetational pattern, linear tonal variation, short strike ridges and at places by linear photo-textures. The data identified under stereomodels through convergence of recognition elements were plotted on the overlays. These linear datas were subjected to analytical rigour to obtain stress trajectories in the area.

Analytical Treatment Of Micro-Lineaments

The joint controlled micro-lineament data were subjected to analytical rigour through statistical method to obtain geological interpretations in terms of macro structural fabric and stress trajectories that led to the evolution of the fabric in a cratonic regime.

The bedding planes were recorded on the geological map (Fig. 1) their spatial disposition and inclination were interpretated in terms of fold geometry and axial directions. On the basis of the homogeneity of patterns the mapped area was delineated into three sub-areas designated as sub-area I, sub-area II, and sub-area III (Fig. 7)

TOTAL OF MICRO-LINEAMENTS

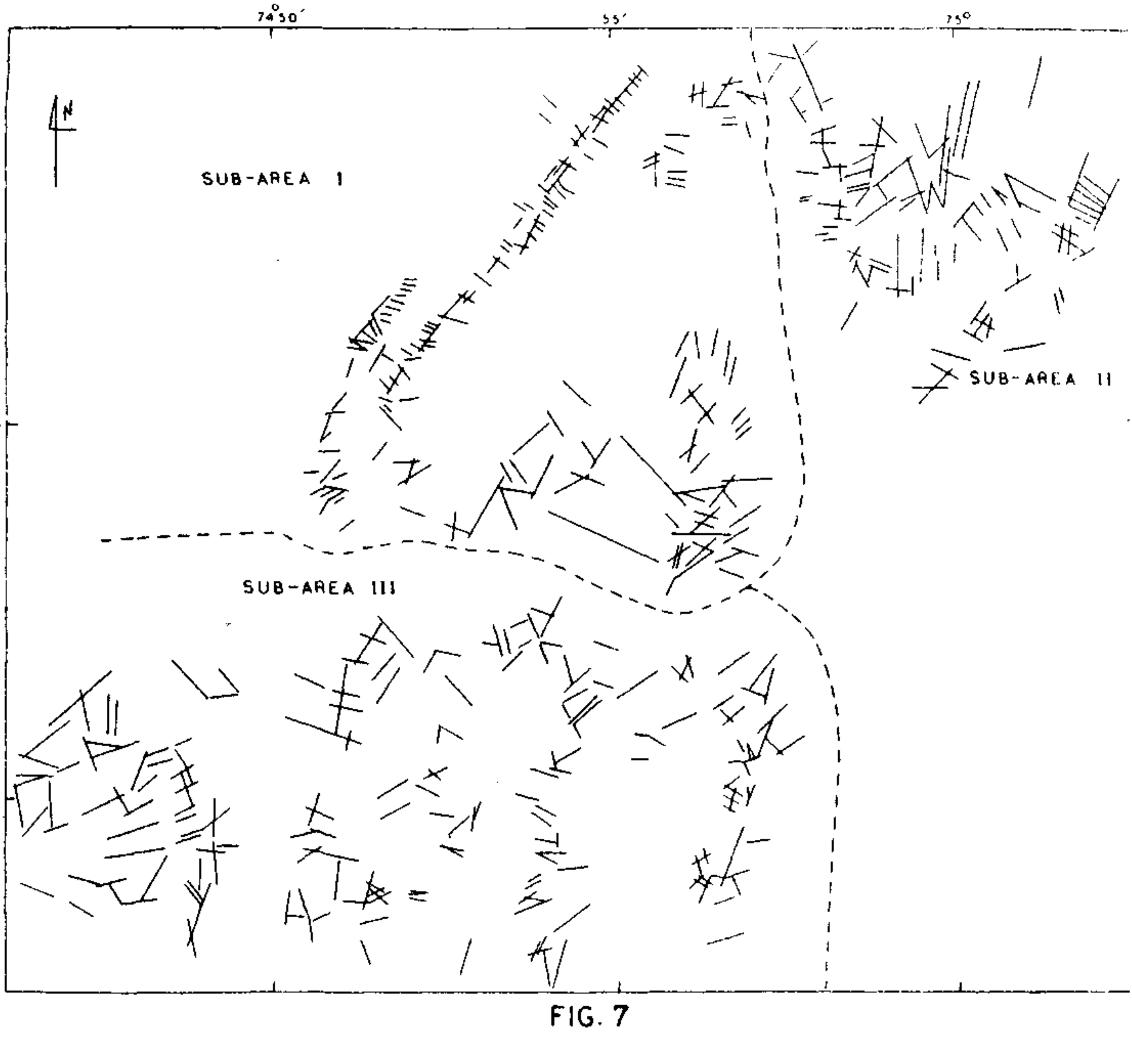


FIG. 7

The micro-lineament, were plotted on the overlays with reference to the map co-ordinates and were subjected to statistical study of their trend, intersection density and incidence density in an attempt to analyse and interpret σ_1 trajectories in the Parsoli-Bichor area of the Vindhyan Basin.

Trend Analysis of Micro-Lineament :

The azimuthal orientation of the micro-lineament seen in the three sub-areas of the Parsoli-Bichor syncline were measured and tabulated. These data were treated statistically through circular histograms. The class interval of 20° was taken and micro-lineament data were plotted in azimuth l classes by assuming a scale of 1 to 1 for micro-lineament. The micro- lineament circular histograms were prepared for sub-area I, II and III (Fig. 13). The micro-lineament azimuthal trends were obtained through circular histograms and were subjected to mathematical mean analysis to obtain cardinal micro-lineament directions. The cardinal micro-lineament directions were computed for each sub-area. From these cardinal directions conceptual kinematic models for stress distribution system of the sub-areas were computed. The basic assumption in this analysis has been that the fracture patterns obtained from stereomodels represent first order joints genetically related to stress regime operative in cratonic basin.

AZIMUTHAL ORIENTATION OF MICRO-LINEAMENTS
IN PARSOLI-BICHOR SYNCLINE
CHITTORGARH, RAJASTHAN

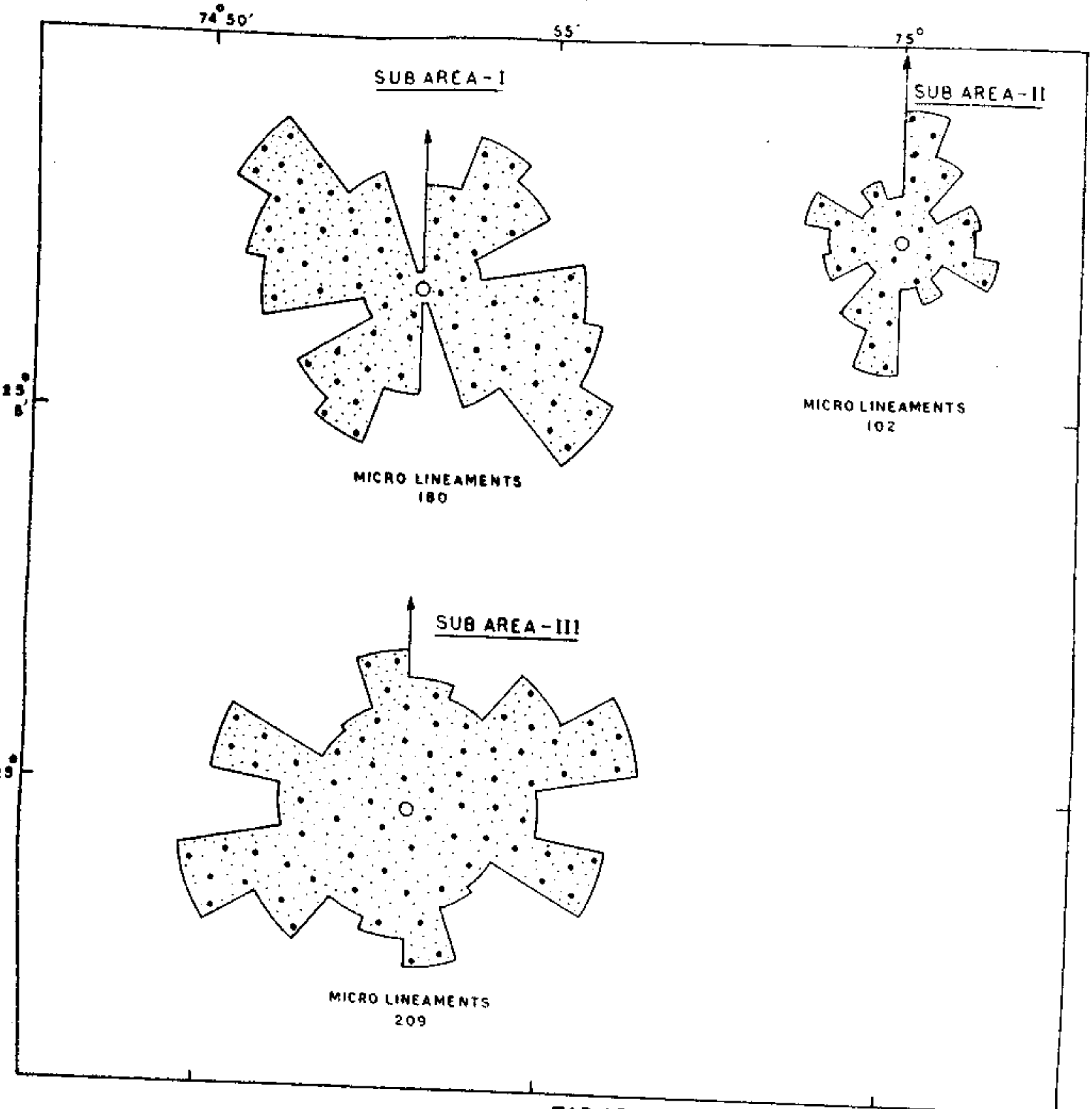


FIG.13

Analysis of Data :

Sub-Area I : In sub-area I the dominant azimuthal classes lie within $0^{\circ}N$ to $60^{\circ}N$ and $80^{\circ}N$ to $160^{\circ}N$. Mathematical means of the azimuthal classes of the sub-area are $30^{\circ}N$ and $120^{\circ}N$ respectively which give the orientation of the cardinal micro-lineament of this sub-area (Fig. 14).

Sub-Area II : In sub-area II the dominant azimuthal classes lie within $0^{\circ}N$ to $40^{\circ}N$ and $60^{\circ}N$ to $120^{\circ}N$. Mathematical means of the azimuthal classes of the sub-area are $20^{\circ}N$ and $90^{\circ}N$ respectively which give the cardinal micro-lineament trends of the sub-area (Fig. 14).

Sub-Area III : In sub-area III the micro-lineament exhibit near isotropic distribution of the azimuthal classes. However, on the basis of dominance of azimuthal densities a major trend has been identified between $40^{\circ}N$ to $220^{\circ}N$ and a minor trend from $120^{\circ}N$ to $220^{\circ}N$. This will give meathematical mean as $80^{\circ}N$ and $170^{\circ}N$ respectively corresponding to the cardinal micro-lineament trends in the sub-area (Fig. 14).

Lineament Intersection Density :

The fracture pattern recognised on the ground in the Parsoli-Bichor area of the Vindhyan Basin gives an isotropic azimuthal picture and no meaningful interpretation in terms of stress trajectories is possible from these elements of petrified

CONCEPTUAL KINEMATIC MODEL FOR STRUCTURAL EVOLUTION OF VINDHYAN BASIN IN PARSOLI-BICHOR SYNCLINE CHITTORGARH, RAJASTHAN

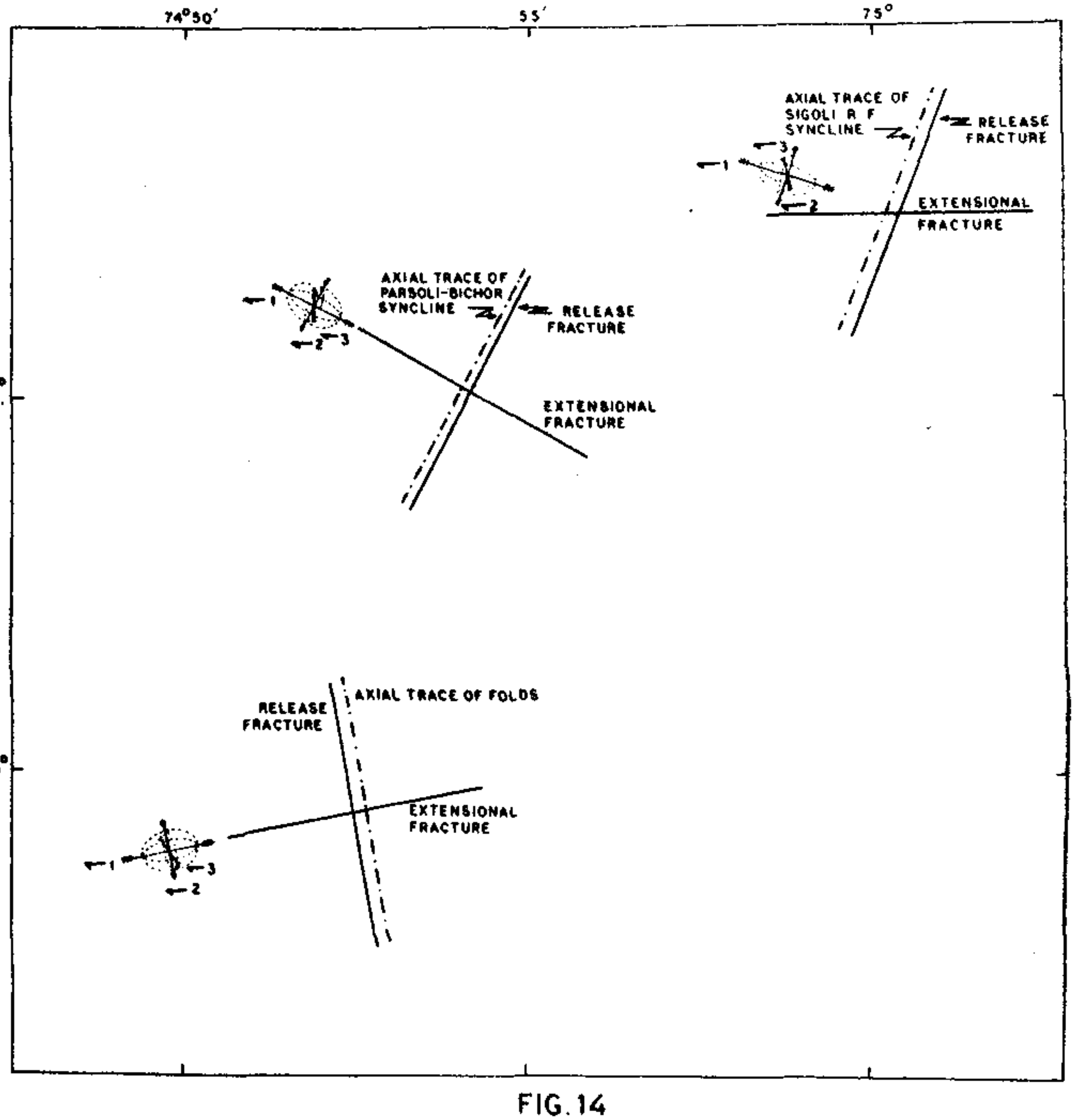


FIG. 14

geometry (Iqbaluddin op. cit.). Under stereomodels the second order fractures formed due to modified stress trajectories (Moody and Hill 1956, Chinnery 1966) are filtered out due to resolution factor in aerial photography. The micro-lineaments picked up from aerial photographs represent first order fractures (joints) formed due to primary stresses. The rational of the present study is that intersecting fractures developed during folding will have genetic and geometric relationship with the stress regimes of the folded sequence. The trend of the intersection maxima will have correlation with the axial trace of the fold. It will be either parallel or normal to the principal elongation in a cratonic regime. Therefore the present study was directed to evolve σ_1 independently from linearity trend of the intersection density contours in the area.

The entire area was sub-divided into 10.24 sq. km. cells. The cell boundaries are so chosen that as far as possible each cell within the studied area has some value of micro-lineament intersection (Fig. 8). The number of joint intersections present per cell was plotted as cell value in the central part of the cell. The area was subsequently contoured by extrapolation method to prepare joint intersection density contour map (Fig. 9). The contour maxima exhibit linearity of pattern which roughly correspond to 43°N, 38°N, 44°N and 43°N in sub-areas I and III. In sub-area II the maxima exhibit 88°N trend.

MICRO-LINEAMENT INTERSECTION DENSITY DISTRIBUTION
OF PARSOLI-BICHOR SYNCLINE
CHITTORGARH, RAJASTHAN

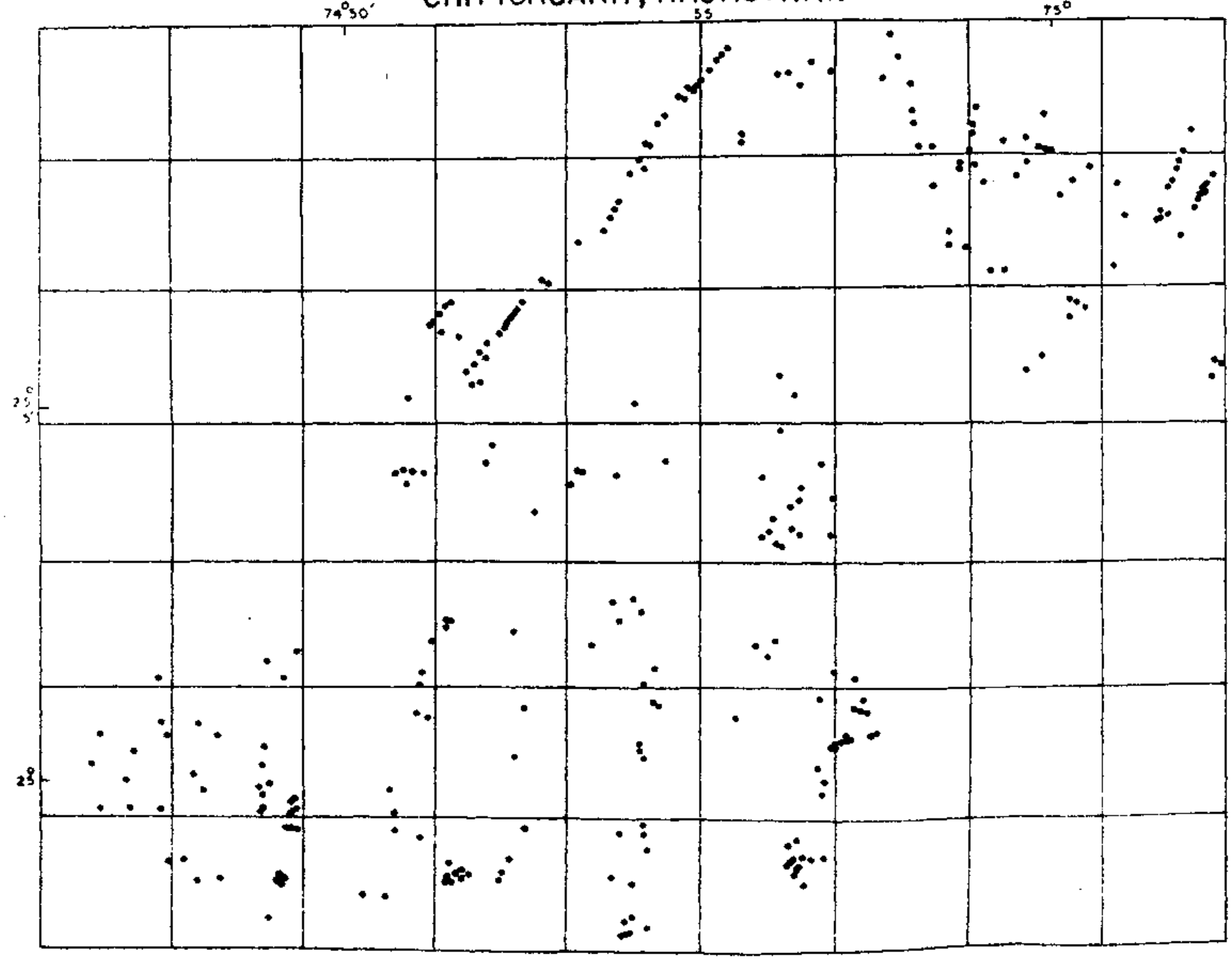
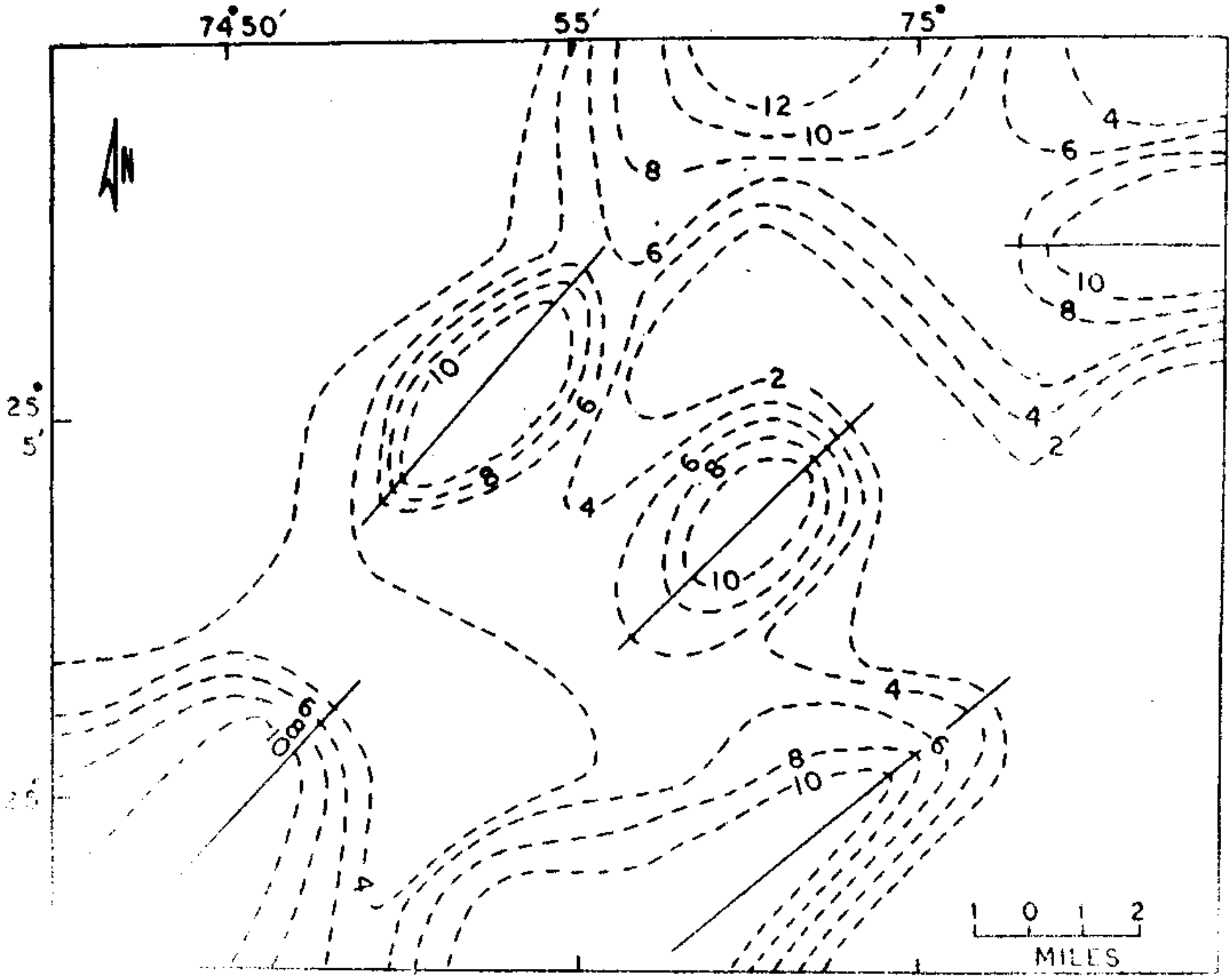


FIG.8



JOINT INTERSECTION DENSITY CONTOUR MAP

FIG. 9

Trend Surface Analysis of micro-lineament intersection density :

Inhomogeneities caused in the spatial distribution of the micro-lineament intersection density, because of surficial cover and absence of mutually intersecting micro-lineaments in certain areas, were smoothened out by subjecting the data to trend surface analysis by moving averages method. Two dimensional smoothening of the intersection density data was achieved by providing 88.89% overlap. The cell distribution grid adopted during intersection density contour analysis (Fig. 8) was maintained. The cell value was calculated for each cell by measurement of the number of micro-lineament intersections per cell and were plotted in the central part of the cell as cell value. The Rolling Mean Analysis was attempted for each cell and was computed by giving 88.89% overlap and twice weightage to the cell value of the central cell by using expression,

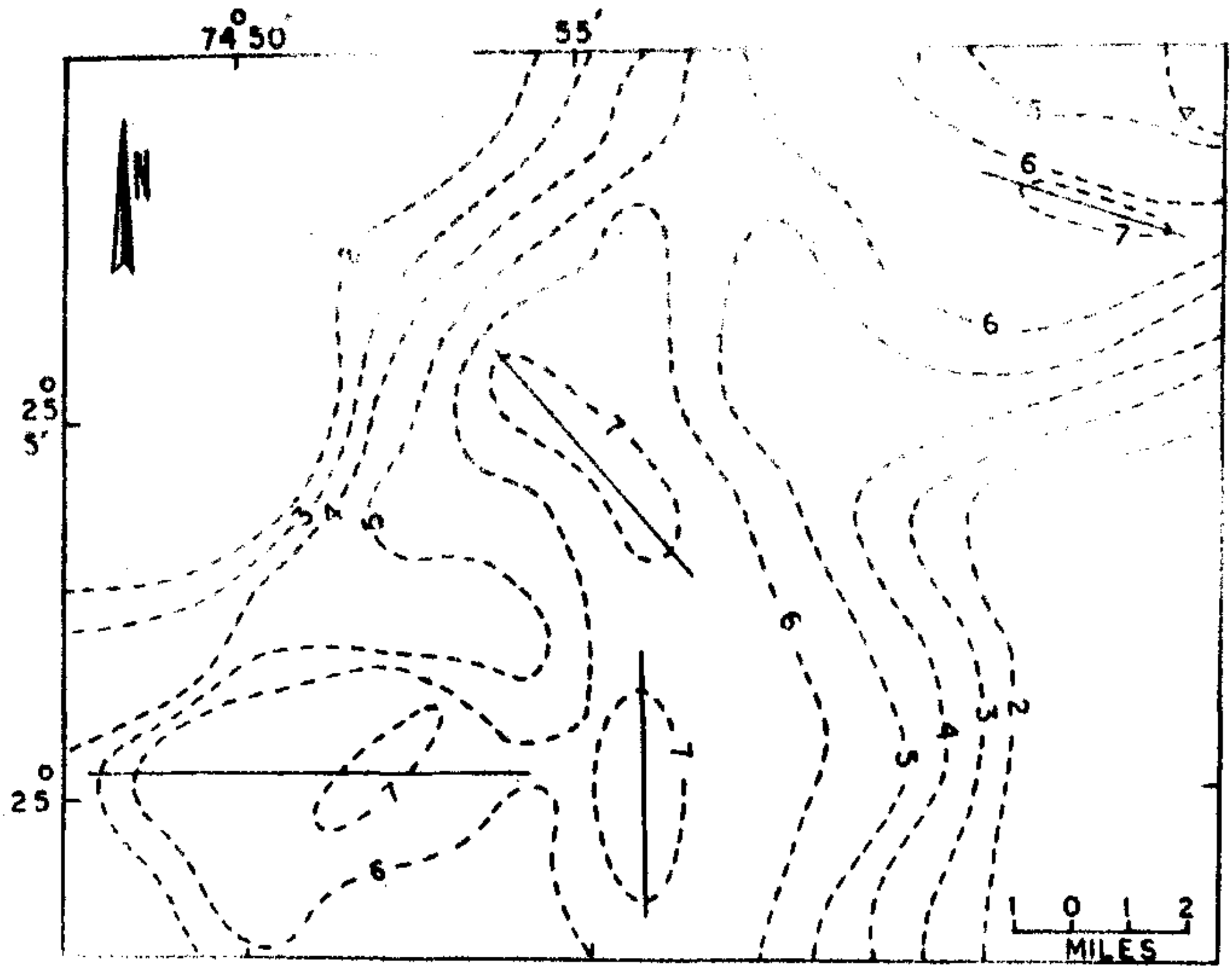
$$Md = \frac{\sum d + 2D}{n}$$

Where Md = Rolling mean of micro-lineament intersection density value of the central cell.

$\sum d$ = Total of the cell value of the micro-lineament intersection density of the overlap area.

D = Cell value of the micro-lineament intersection density of the central cell.

n = Total number of cells.



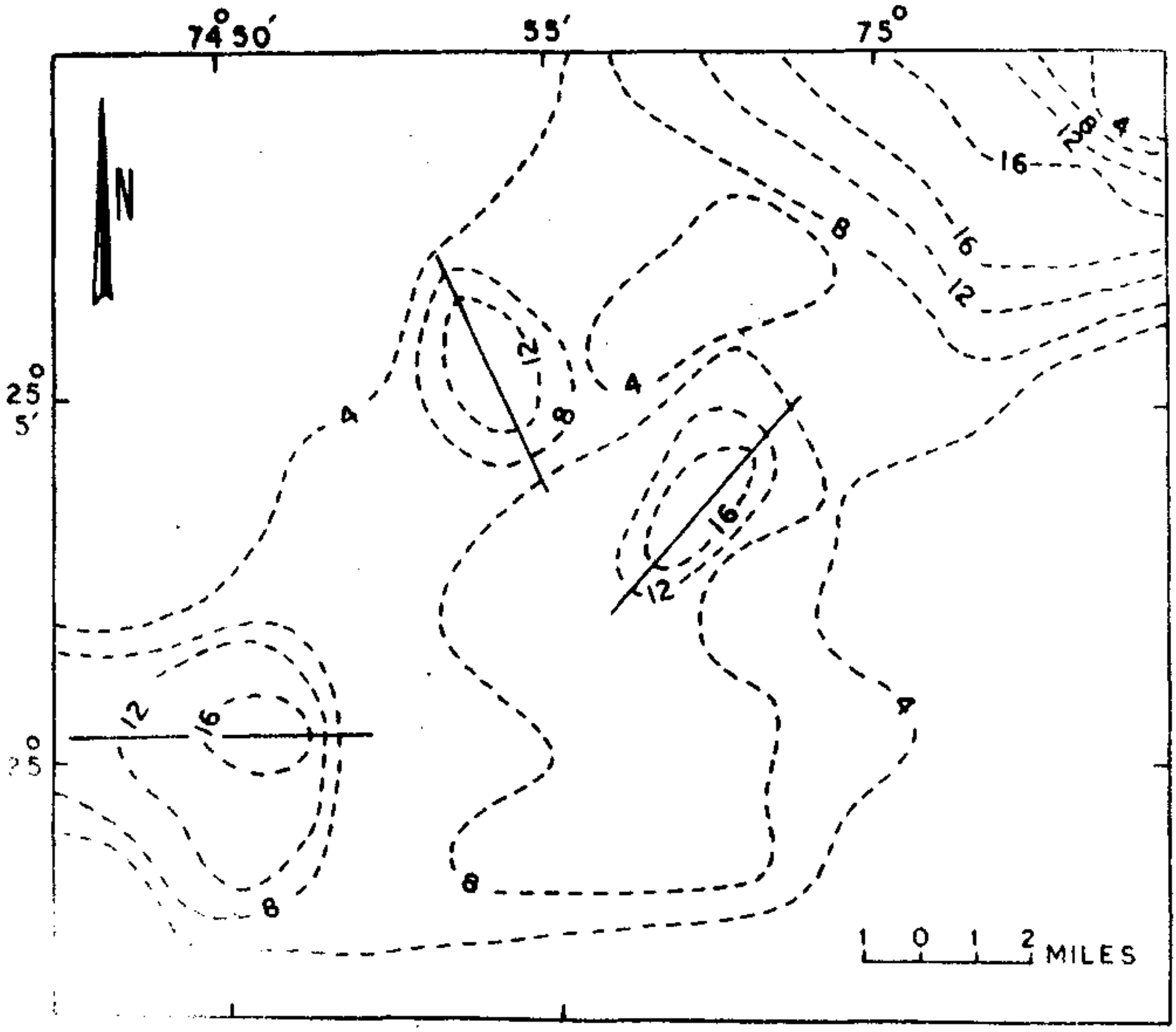
JOINT INTERSECTION TREND SURFACE MAP
FIG 10

The values so obtained were plotted as Rolling Mean Values of the central cell on the working sheet taking those Rolling Mean Values as controls, trend surface contours were prepared by extrapolation technique. The micro-lineament intersection density maxima were plotted on the trend surface map (Fig. 10). The intersection density trend surface maxima are 140°W in the sub-area I, 105°W in sub-area II and East-West in sub-area III.

Micro-Lineament Incidence Analysis

Micro-lineament incidence analysis was attempted in an effort to observe if any meaningful correlation can be established between micro-lineament incidence and the structural fabric of the area. This study was carried out as an ancillary to the main strain analysis techniques of the statistical treatment of azimuthal trends of micro-lineaments and their intersection densities in the area.

The cell grid adopted for the micro-lineament intersection density studies were maintained. The length of individual micro-lineaments within each cell were measured and the summation of the micro-lineament incidence per cell were computed and plotted on the overlay in the central part of the cell as cell value. The area was contoured by extrapolation technique and the micro-lineament incidence density contour map was prepared (Fig. 11). This map does not show any homogeneity of style or pattern and as such can not be of much use for analytical purpose.



JOINT INCIDENCE DENSITY CONTOUR MAP

FIG. 11

Trend Surface Analysis of Micro-Lineament Incidence Density :

Inhomogeneities caused in the spatial distribution of the micro-lineaments due to surficial cover or the absence of lineament incidence were smoothened out by giving 88.89% overlap to each cell value. The two dimensional smoothening of the micro-lineament incidence density values of the individual cells were carried out by moving average method and Rolling Mean Values for each cell were obtained by using expression,

$$Md_i = \frac{\sum d_i + 2D_i}{n}$$

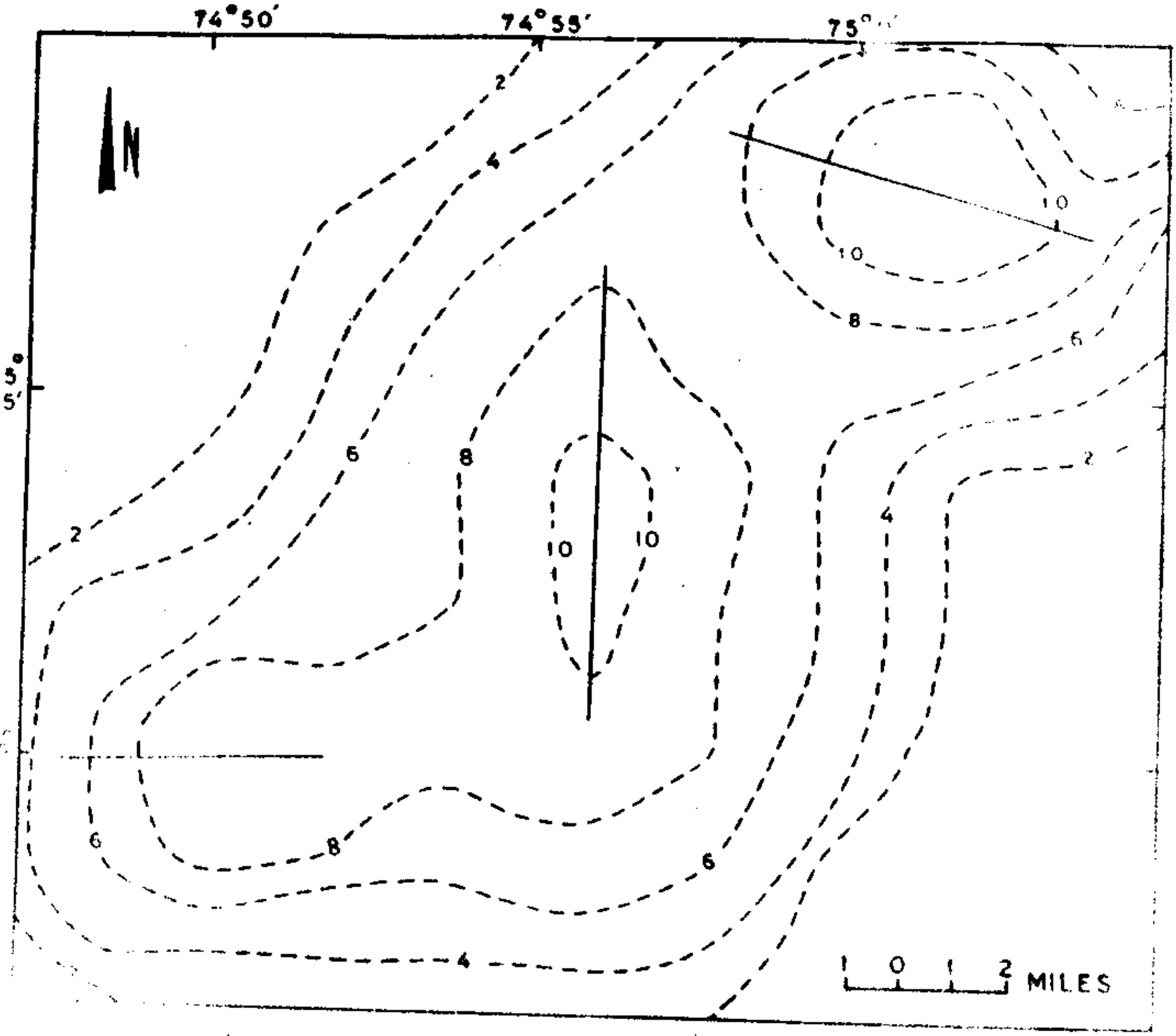
Where Md_i = Rolling Mean of micro-lineament incidence density value of the central cell.

$\sum di$ = Cell value of the micro-lineament incidence density of the overlap area.

D_i = Cell value of the micro-lineament incidence density of the central cell.

n = Total number of cells.

The Rolling Mean Values so obtained were plotted on the working sheet for each cell and the trend surface contour map was prepared by extrapolation technique and the trends of the maxima were plotted.(Fig. 12).



...idence trend surface map of Parsoli- Bichor syncline
Chittorgarh, Rajasthan
Fig. 12

CONCURRENCE AND SYNTHESIS

Conceptual Kinematic Model For The Structural Evolution of the Parsoli - Bichor Syncline

Concurrence and synthesis of the data generated through photogeophysics and patterns obtained by statistical treatment of the structural data has led to the development of conceptual kinematic model to explain the structural evolution of the Parsoli-Bichor syncline.

Axial Trace Geometry

The axial traces for the major folds of the area were plotted from stereomodels and the geometry of the folded surface was evaluated from orientation of the bedding planes. The axial trends of sub-area I is 30°N, sub-area II is 20°N and sub-area III is 170°N to 180°N. From the orientation of the axial traces which represents direction of maximum elongation, direction of maximum compressive principal stresses were computed as given in Table III below.

Table III

Sub-Area	Axial Trace Orientation	σ_1 Trajectory
I	N30°E - S30°W	N60°W - S60°E
II	N20°E - S20°W	N70°W - S70°W
III	N10°W - S10°E	N80°E - S80°W

Micro-Lineament Geometry

Trend Analysis

The micro-lineaments observed under the stereomodels are fractured controlled. The trend analysis of the azimuthal variance carried out to obtain cardinaltrends for the three sub-areas exhibit general geometrical relationship with the axial orientation and the trajectories in the three sub-areas as given in Table IV below.

Table IV

Sub-Area	Cardinal Azimuthal Trends of Micro-Lineaments		Axial Trace Orientation	σ_1 Trajectory
I	N30°E-S20°W	N60°W-S60°E	N30°E-S30°W	N60°W-S60°E
II	N20°E-S20°W	E-W	N20°E-S20°W	N70°W-S70°E
III	N10°W-S10°E	N80°E-S80°W	N10°W-S10°E	N80°E-S80°W

The cardinal azimuthal trends of the micro-lineaments exhibit general geometrical correlation with the axial trace directions and σ_1 trajectories. It follows from it that genetically these fractures can be classed as extensional fractures and release fractures. The development of the extensional fracture is related to the tensile regime developed in the direction of maximum elongation during folding thus the sets of fractures exhibit general directional correlation with the σ_1 trajectories in the three sub-areas. After the compressive stresses died out the area was subjected to tensile regime which developed in the direction of maximum compressive shortening as a result the release fractures developed normal to the direction of maximum compressive shortening and parallel to axial traces in the three sub-areas. Thus it will be seen that apparently inhomogenous fracture patterns have an inherent and orderly genetic control related to the palaeo-stress patterns in the different areas of the Parsoli-Bichor syncline.

Variable Stress Trajectory

In the Parsoli-Bichor syncline the stress trajectory exhibits variations. These variations have been possibly controlled by the local variations of the pre-Vindhyan grains of the Great Boundary Fault in the three sub-areas. The stress regime in cratonic basin will be intra-basinal, the force will be generated through the resolution of the body force of the sedimentary pile against the basin floor. The force will get resolved into two components, one will be acting perpendicular to the basin floor and will control the bathymetry of the basin and the other will be parallel to the basin floor and will lead to deformation of the sedimentary pile (Iqbaluddin, 1980). The resolved horizontal component of the body force of the sedimentary prism will be multi-directional and will act against the basin margin, it will generate stress whose trajectories will be controlled by the grain of the rigid basement (Iqbaluddin et al., 1978). Thus in the present area the variable trends of the can be explained due to local inhomogeneities of the basin margin. There general trend of the Great Boundary Fault is 30°N in the northern part of the area and it veers to north-south in the southern part of the Vindhyan Basin near Chittorgarh (Iqbaluddin et. al. op. cit.). Thus the variable trends in the sub-area I and sub-area III will be reconciled as cogenetic trajectories resulting from adjustment of forces perpendicular to the grain of the basin margin where the compressive stress will be maximum.

Micro-Lineament Intersection

In order to obtain relationship between σ_1 and micro-lineament intersection density a study was attempted to obtain correlation between the micro-lineament intersection trend and σ_1 trajectories independently computed from axial trace directions and fracture patterns. The major anomaly trends obtained for intersection densities by trend surface analysis and extra-polarity contouring are given in the Table V below.

Table V

Sub-Area	Orientation of Micro lineament intersection density contour maxima	Orientation of micro lineament intersection trend surface maxima	σ_1 Trajectory
I	N43°E - S43°W	N40°W - S40°E	N60°W - S60°E
II	N88°E - S88°W	N75°W - S75°E	N70°W - S70°E
III	N44°E - S44°W	East - West	N80°E - S80°W

It will be seen from table above that micro-lineament intersection density maxima obtained from trend surface analysis by two dimensional smoothening exhibit general correlation with maximum principal stress directions in the different sub-areas. Slight variance in the trends perhaps is due to paucity of controls in the area. The anamoly trends obtained from intersection density contour maxima does not exhibit any homogeneity of pattern except in sub-area II where the anamoly trends obtained from density contouring and trend surface analysis exhibit some directional correlation. It is, therefore, felt that in areas of low intersection densities meaningful patterns can be obtained by trend analysis as attempted in the present study.

Micro-Lineament Incidence

To obtain independent relationship between micro-lineament incidence and stress distribution system in a cratonic regime correlation was attempted between micro-lineament incidence maxima obtained from extrapolatory contouring and trend surface analysis. The orientation of the micro-lineament maxima for the three sub-areas has been given in Table VI below.

Table VI

Sub-Area	Orientation of micro-lineament Incidence Density Maxima	Orientation of micro-Lineament Trend Surface Maxima	σ_1 Trajectory
I	N38°E - S83°W, N23°W - S23°E	N3°E - S3°W	N60°W - S60°E
II	Absent	N70°W - S70°E	N70°W - S70°E
III	N80°E - S80°W	N85°E - S85°W	N80°E - S80°W

The micro-lineament incidence density maxima does not exhibit any meaningful correlation between the σ_1 trajectories and the micro-lineament incidence density maxima trends, except in sub-area III. Smoothening the distributional inhomogeneity by Rolling Mean Analysis suggests meaningful correlation between the micro-lineament trend surface maxima and the stress distribution system. The area represents a cratonic regime and intrabasinal stress environment. In an intrabasinal environment the dominant fracture regime will be tensile which will operative during and after deformation. In sub-area I the dominant micro-lineament trend surface maxima follows N3°E - S3°W trend, which is apparently incongruous to the σ_1 trajectory of the compressive stress regime but a close look on the photogeological map (Fig. 1) of the area suggests the development of roughly East-West culmination axis between sub-area I and sub-area III. The tensile stress regime corresponding to the culmination axis will be North-South in sub-area I and adjacent part of sub-area III. The micro-lineament incidence trends viewed in the context of the tensile stress regime of sub-area I will suggest a correlation between the micro-lineament incidence trend surface maxima and tensile stress trajectories. In sub-area II and III,the micro-lineament incidence maxima and σ_1 trajectories exhibit good correlation. It is,therefore, concluded that trend surface analysis of micro-lineament incidence densities can be useful tool for stress analysis of tensile regimes in cratonic basin. This technique of trend surface analysis inspires hope for developing conceptual models of inaccessible areas and areas with low incidence and intersection densities of fracture patterns. It can serve useful purpose for studies of stress distribution in slightly to moderately deformed petroliferous basin and for location of drill-site,etc., in oil exploration.

Chapter V

SUMMARY AND CONCLUSION

The present study was directed to investigate the photogeology, geomorphology and structural fabric of the Parsoli-Bichor area, Chittorgarh district, Rajasthan. The study was carried out through stereomodel observation and was extended to an area of about 350 sq. km. in parts of the Vindhyan Basin of Rajasthan. The area is included in parts of Survey of India toposheet no. 45K/16. Photo coverage of the area on scale of 1 : 63,360 was used. Data generation of the geological structural and geomorphic elements in the area was carried out through concurrence and synthesis of spectral and geotechnical characters. The stratigraphy has been established by scanning of external reference data.

Model for the geomorphic evolution in parts of Vindhyan Basin in Rajasthan was worked out by study of spectral and geotechnical expressions of constructional and erosional landforms under stereomodels. The landscape evolution has been assigned to three cycles. The first cycle was erosional which gave rise to Parsoli surface roughly corresponding to 432 m. elevation dominantly by process of sheet-wash. The second cycle was controlled by deep chemical weathering followed by sheetwash. It led to development of Berach Surface corresponding to 379 m. elevation. The generation of this surface led to lowering of base level of erosion and initiated gully erosion on the Parsoli Surface. It generated landscape inhomogeneities manifested as Structural Hills, Structural

Valleys, Erosional Valleys, Cuestas, Hogbacks, Conical Hill, Mesa, Pediment, Fan, Escarpment and Rolling Plains. Local pauses in the erosive activity have taken place as seen by development of buried pediments in the area. The aggradational phase possibly represent micro-process in the total model of landscape evolution of Vindhyan Basin in Rajasthan which has been dominantly erosive. The third cycle of landscape evolution is characterised by valley deepening of the drainage channels through cutting of their own aggradational surfaces (buried pediment) which was possibly triggered by lowering of base level of erosion subsequent to the generation of Berach Surface as indicated by the mature stage in the valley development of the Berach river. The local relief characteristics of basic geomorphic units in the Vindhyan Basin appears to have been shaped by the third cycle which is till in its dynamic phase.

To establish photo characters of the lithology and structural elements in the Vindhyan Basin of Rajasthan, variable tonal densities, erosional resistance, drainage pattern, density and channel profile together with landuse pattern, vegetation and structural expressions have used as recognition elements. The stratigraphy of the Vindhyans in the area has been established with the help of photocharacters together with spatial relationship of the lithounits and external reference data. The following order of superposition has been established,

Table I

LITHOSTRATIGRAPHY

Vindhyan Super-Group	Upper Vindhyan	Bhander Group	Bhander Sandstone	1.4-0.7 b.y.
			Samria Shale	
			Bhander Limestone	
			Ganurgarh Shale	
		Rewa Group	Rewa Sandstone	
			Rewa Shale	
		Kaimur Group	Kaimur Sandstone	
	Lower Vindhyan	Khorip Group	Suket Shale	

---------------Great Boundary Fault---------------

Mangalwar Complex	2.5 b.y.

(Modified after Prasad, B., 1981)

The present study has established that the photo-recognition characters based on reflectance and landform characteristics can serve as guides for rapid lithological and geomorphological mapping in the Vindhyan Basin of Rajasthan.

Structural geometry of the area was worked out through study of strain generated photo-fabric. Structural data was generated through photogeophysical and photogeological interpretations. The fold geometry was evaluated through varaince of strike and dip of the plain of stratification. Joint controlled micro-lineament were utilised to obtain macro-fabric and stress trajectories that led to the evolution of the structural fabric in cratonic regime.

The micro-lineament analysis was carried out through statistical studies of their trend intersection density and incidence density. The maxima obtained from statistical treatment were interpreted in relation to σ_1 trajectories. On the basis of homogeneity of the style the area has been delineated into sub-areas I, II & III. The dominant axial trace orientations of sub-areas I, II & III have been $30^{\circ}N$, $20^{\circ}N$ and $170^{\circ}N$ and corresponding σ_1 trajectories have been $120^{\circ}N$, $110^{\circ}N$ and $80^{\circ}N$ respectively.

Azimuthal orientation of micro-lineaments was statistically treated through circular histograms with the class interval of 20°. The dominant micro-lineament azimuthal trends were subjected to mathematical mean analysis to obtain cardinal micro-lineament incidence. The cardinal micro-lineament direction were used for preparation of conceptual kinematic model for stress distribution system in the area.

The micro-lineament intersection densities were used for computation of σ_1 trajectories independently of the trend analysis. The area was divided into a convenient grid of 10.24 sq. km. cells. The cell values of the cells in terms of micro-lineament intersection density were computed and the area was contoured by extrapolation technique. The contour maxima were obtained and correlation between the maxima and the σ_1 trajectories for the sub-areas were attempted. Apart, trend surface analysis of micro-lineament intersection density were also attempted. to achieve two dimensional smoothening of the intersection density data. The cell values were smoothened out through Rolling Mean Analysis by providing 88.89% overlap to each cell. The Rolling Mean Values of the cells were used for preparation of trend surface contours. Intersection density maxima of the trend surface contours were plotted and correlated with the stress regime.

Micro-lineament incidence analysis was attempted in an effort to observe if any meaningful correlation can be established between micro-lineament incidence and the structural fabric of the area. During this study the grid adopted were micro-lineament intersection density studies were maintained and the summation of the length of individual micro-lineaments were plotted as cell values. The area was contoured to obtain micro-lineament incidence density contours maps. The inhomogeneities caused in the spatial distribution of micro-lineament due to surficial cover or absence of lineament incidence were smoothened out through trend surface analysis. The Rolling Mean Analysis of the area was attempted by providing 88.89% overlap and twice the weighhage to the central cell. The Rolling Mean Values so obtained were used to prepare trend surface contour map of the area and obtaining trends of maxima of micro-lineament incidence.

The concurrence and synthesis of the micro-lineament intersection density, azimuthal orientation and incidence maxima suggest good correlation with σ_1 trajectories of the various sub-areas. It has been observed that the fracture pattern exhibits a model of tensile regime in the Vindhyan Basin of Rajasthan. Genetically the failure has been either as extensional fractures or as release fractures. This technique of trend surface analysis may prove useful in areas of low micro-lineament incidence and intersection densities. It can serve useful purpose for studies of stress distribution in slightly to moderately deformed petroliferous basins and for locating the areas of tension so essential in oil exploration.

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APPENDIX

MICRO-LINEAMENT TRENDS

SUB-AREA I

0°N	30°N	48°N	83°N	282°N	295°N	312°N	328°N
0°N	31°N	49°N	83°N	283°N	296°N	313°N	328°N
0°N	32°N	49°N	83°N	284°N	296°N	313°N	329°N
2°N	33°N	50°N	83°N	284°N	297°N	313°N	329°N
2°N	36°N	50°N	84°N	286°N	300°N	314°N	332°N
3°N	37°N	51°N	85°N	286°N	301°N	314°N	333°N
9°N	38°N	52°N	87°N	289°N	301°N	315°N	334°N
12°N	38°N	54°N	88°N	289°N	301°N	315°N	335°N
13°N	38°N	56°N	88°N	289°N	302°N	316°N	336°N
14°N	38°N	58°N	88°N	290°N	303°N	317°N	340°N
14°N	39°N	58°N	88°N	290°N	303°N	318°N	356°N
16°N	39°N	59°N	89°N	290°N	306°N	318°N	358°N
19°N	39°N	59°N	90°N	290°N	306°N	318°N	
20°N	39°N	61°N	90°N	291°N	306°N	319°N	
21°N	40°N	61°N	271°N	291°N	306°N	319°N	
23°N	41°N	62°N	272°N	291°N	307°N	321°N	
24°N	41°N	63°N	273°N	292°N	307°N	322°N	
25°N	43°N	64°N	274°N	292°N	308°N	322°N	
26°N	44°N	65°N	278°N	292°N	308°N	324°N	
26°N	45°N	70°N	278°N	293°N	309°N	324°N	
27°N	45°N	72°N	280°N	293°N	310°N	324°N	
28°N	46°N	81°N	280°N	295°N	312°N	325°N	
[illegible]°N	46°N	81°N	280°N	295°N	312°N	325°N	
30°N	48°N	82°N	281°N	295°N	312°N	326°N	

SUB-AREA II

0°N	13°N	45°N	80°N	293°N	322°N
0°N	15°N	50°N	81°N	295°N	325°N
0°N	16°N	54°N	84°N	295°N	326°N
0°N	21°N	55°N	86°N	296°N	327°N
0°N	23°N	58°N	89°N	296°N	327°N
3°N	23°N	60°N	90°N	297°N	331°N
5°N	27°N	63°N	90°N	298°N	334°N
5°N	30°N	68°N	273°N	300°N	337°N
8°N	31°N	69°N	275°N	300°N	339°N
8°N	31°N	73°N	276°N	301°N	340°N
8°N	31°N	75°N	277°N	304°N	341°N
10°N	34°N	76°N	280°N	306°N	344°N
11°N	36°N	76°N	282°N	309°N	344°N
11°N	36°N	76°N	286°N	310°N	348°N
12°N	36°N	76°N	287°N	313°N	351°N
12°N	37°N	79°N	289°N	315°N	356°N
12°N	37°N	80°N	291°N	315°N	358°N

SUB-AREA III

0°N	24°N	52°N	68°N	83°N	284°N	305°N	340°N
0°N	25°N	55°N	69°N	85°N	287°N	305°N	341°N
0°N	25°N	55°N	69°N	88°N	288°N	308°N	341°N
0°N	27°N	55°N	70°N	90°N	288°N	312°N	341°N
0°N	30°N	56°N	70°N	90°N	288°N	313°N	341°N
1°N	32°N	56°N	70°N	90°N	289°N	313°N	342°N
2°N	33°N	56°N	70°N	274°N	289°N	313°N	342°N
2°N	34°N	56°N	70°N	276°N	289°N	317°N	343°N
5°N	34°N	56°N	70°N	277°N	290°N	318°N	343°N
7°N	34°N	57°N	70°N	277°N	290°N	318°N	343°N
8°N	38°N	58°N	72°N	278°N	290°N	319°N	344°N
9°N	39°N	59°N	73°N	279°N	291°N	321°N	344°N
11°N	42°N	60°N	73°N	280°N	293°N	321°N	345°N
12°N	44°N	61°N	75°N	280°N	294°N	322°N	346°N
12°N	45°N	61°N	75°N	280°N	295°N	324°N	348°N
12°N	45°N	[illegible]°N	75°N	280°N	297°N	325°N	348°N
14°N	46°N	63°N	75°N	281°N	299°N	326°N	348°N
19°N	46°N	63°N	75°N	281°N	300°N	326°N	348°N
19°N	47°N	63°N	75°N	281°N	300°N	327°N	348°N
20°N	47°N	64°N	78°N	281°N	300°N	328°N	350°N
21°N	48°N	65°N	80°N	281°N	300°N	329°N	351°N
22°N	49°N	65°N	80°N	283°N	301°N	329°N	352°N
23°N	49°N	65°N	81°N	283°N	30[illegible]°N	330°N	354°N
23°N	49°N	66°N	81°N	283°N	303°N	337°N	355°N
24°N	51°N	67°N	82°N	284°N	303°N	339°N	356°N
24°N	52°N	[illegible]°N	83°N	284°N	305°N	340°N	358°N
							358°N